Rural Electrification Administration
Telecommunications Engineering and Construction Manual

Section 452.1
Issue No. 1
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TELEPHONE CABLE PAIR HARMONIC ANALYSIS

CONTENTS

<u>FIGURES</u>:

1. GENERAL

GDS

1.1 This section provides REA borrowers, consulting engineers, contractors and other interested parties with technical information for use in the design and construction of REA borrowers telephone systems. It is written to provide an understanding of cable pair power influence harmonic analysis during noise investigations.

1.2 This section is issued to present techniques for the measurement and analysis of the harmonic content of the noise-to-ground or power influence on a cable pair. It is a specialized technique for application where noise investigation procedures performed by crafts people have failed to find a solution to the problem. The technique is a diagnostic tool recommended as the initial action where a need for specialized procedures has been established. Study of the recorded results from these measurements may appear to provide sufficient information to determine appropriate corrective action. Such action should not be initiated without additional measurements to confirm the analysis. Power influence analysis should be utilized to determine the direction for subsequent investigation thus reducing the time required for completing other advanced measurement procedures.

1.3 A telephone circuit located parallel to a power line can be compared to a probe wire. Probe wire measurements are completed to determine the efficiency of a power system through the magnitude of earth return currents. While the magnitude of earth return current cannot be determined through measurement of the longitudinal induced harmonic voltage

on a telephone circuit valuable information can be obtained relative to power system performance. It has been noted that the harmonic variation measured with a probe wire located beneath a power line will be in close correlation to longitudinal harmonic voltage measurements on a cable pair located parallel to the same power line. Since many power line conditions which can result in telephone system interference have a distinct harmonic pattern or signature they can be identified by measuring the longitudinal harmonic voltage to ground on a cable pair.

2. MEASUREMENT

2.1 Data for analysis is obtained by measuring and recording the noise-to-ground (Ng) or power influence (PI) on a noisy cable pair. For a discussion of noise-to-ground and power influence refer to TE&CM Section 451, Paragraph 12. All harmonic frequencies of the power system fundamental frequency from the first through the forty seventh (60 through 2820 Hertz, inclusive) should be measured and recorded on a data form for power influence analysis.

2.1.1 A sample data form for power influence analysis is shown in Figure 1. This form provides a space for recording the power influence level in dBrn for the harmonic frequencies from 60 through 2820 Hertz. Column 3 lists the average noise levels from a loop study. While the levels should be measured and recorded for all the listed harmonics levels below those shown in column 3 are disregarded during the analysis.

2.1.2 There will be occasions where a frequency other than a harmonic of the fundamental power line frequency will be present as a component of the noise to ground. The level and frequency of these other components should also be recorded.

2.2 Measurements may be made at a subscriber station protector or at either end of an idle pair in a noisy cable. The subscriber station protector is preferred since there should be a good low resistance ground available for connection to the test set.

2.2.1 Where measurements are made at the field end of an idle cable pair there should be a ground rod (with low resistance to earth) or multigrounded neutral connection for ground reference rather than the cable shield alone. The pair is shorted and grounded at the central office.

2.2.2 When an idle pair is measured at the central office the central office ground is available for connection to the test set. The cable pair is shorted and grounded to a low resistance ground such a multi-grounded neutral at the field end. This method is recommended when several pairs of different length are to be measured which would require setting up at several field locations.

2.3 When measurements are to be made with a spectrum analyzer which has the capability of functioning as a noise measuring set the tip and ring conductors of the cable pair or drop are connected to the appropriate terminals of the test set as shown in Figure 2. A connection

HARMONIC ANALYSIS DATA SHEET

Company ______________________________ Date __________

Exchange ______________________________ Time __________

Route ______________________________ Pair __________

Tested By ______________________________

Harmonic	1. Freq. Hz	2. PI Level (Ng+40) (dBrn 3KHz)	3. Disregard If Levels Are Less Than (dBrn 3KHz)	Harmonic	1. Freq. Hz	2. PI Level (Ng+40) (dBrn 3KHz)	3. Disregard If Levels Are Less Than (dBrn 3KHz)
1	60		115	37	2220		37
2	120		106	38	2280		36
3	180		97	39	2380		35
4	240		92	40	2400		35
5	300		83	41	2460		34
6	360		80	42	2520		34
7	420		77	43	2580		34
8	480		77	44	2640		34
9	540		77	45	2700		34
10	600		70	46	2760		34
11	660		65	47	2820		34
12	720		61				
13	780		58				
14	840		57				
15	900		55				
16	960		51				
17	1020		48				
18	1080		47				
19	1140		46				
20	1200		45				
21	1260		44				
22	1320		43				
23	1380		43				
24	1440		42				
25	1500		42				
26	1560		41				
27	1620		41				
28	1680		41				
29	1740		41				
30	1800		40				
31	1860		39				
32	1920		39				
33	1980		38				
34	2040		38				
35	2100		37				
36	2160		37				

Overall Noise Measurement

3kHz.

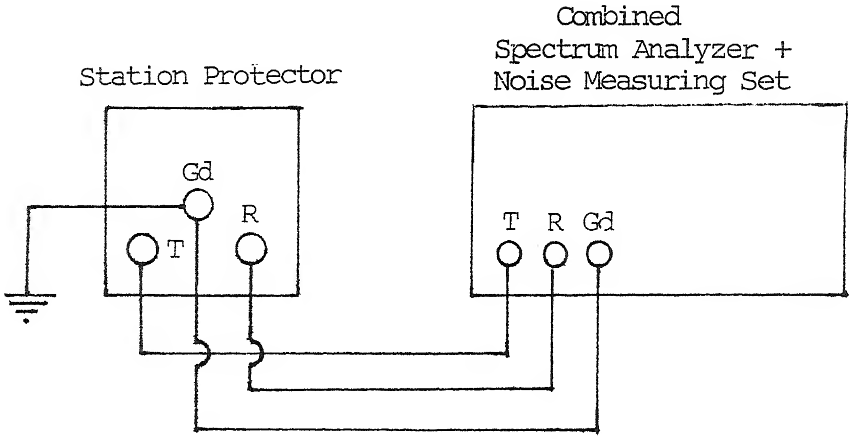
Power Influence (Ng+40) ______ dBrn
Circuit Noise (Nm) ______ dBrn
Balance ______ dB

C-Msg.

Power Influence (Ng+40) ______ dBrnc
Circuit Noise (Nm) ______ dBrnc
Balance ______ dB

FIGURE 1

is established between the ground terminal of the test set and a low resistance ground such as the ground terminal of a subscriber station protector. (See Paragraph 2.2).



SPECTRUM ANALYZER + NOISE MEASURING SET CONNECTIONS

FIGURE 2

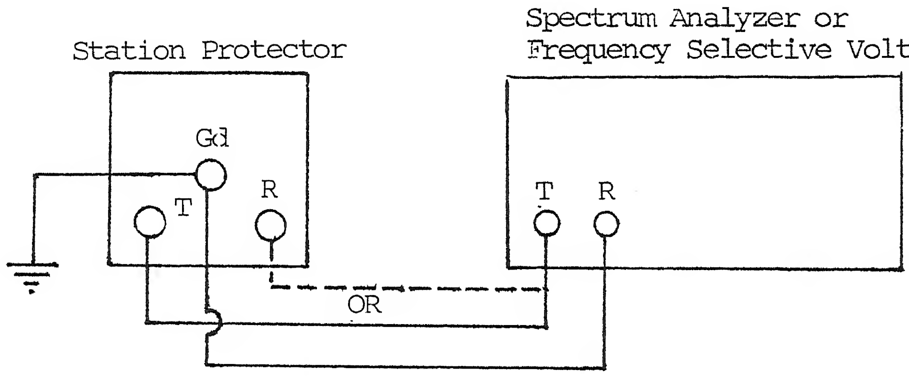
2.3.1 Set the spectrum analyzer to measure noise-to-ground. The weighting switch should be set for 3kHz Flat weighting. The test set should be switched to function as a frequency selective device rather than a noise measuring set.

2.3.2 Where measurements are being made on a working pair first dial the quiet termination and then switch in the holding coil. When an idle pair is used it is only necessary to short circuit and ground the tip and ring of the pair at the central office MDF.

2.3.3 Set the spectrum analyzer to the desired harmonic frequency and read the magnitude in dBrn. Successively read the magnitude of each harmonic frequency starting at 60 Hertz through 2820 Hertz. Values of power influence should be recorded for harmonics of the 60 Hertz fundamental frequency. See paragraph 2.1. Remember to add 40 dB if measurements are in units of noise-to-ground.

2.3.4 Switch the test set to the noise measuring set mode with C-message weighting, read and record the overall power influence in dBrnc. Then switch to measure noise metallic (Nm), read and record the value. These measurements provide data from which the balance of the cable pair may be determined. See TE&CM Section 451, Paragraph 12.3 for a discussion of balance.

2.4 Where measurements are to be made with a spectrum analyzer or frequency selective voltmeter that does not have noise measuring set capability one input terminal is connected to either the tip or ring conductor of the cable pair or drop as shown in Figure 3. The other terminal is connected to a low resistance ground such as the ground terminal of a subscriber station protector (See Paragraph 2.2). The input circuit of the test set should be high impedance (100,000 ohms or greater). For uniformity purposes only, always connect the ring terminal of the test set to the station ground and the tip terminal to either wire of the cable pair under test.



SPECTRUM ANALYZER CONNECTIONS

FIGURE 3

2.4.1 Read the magnitude of each harmonic frequency in dBm, if possible, starting at 60 Hertz through 2820 Hertz. Values should be recorded in dBrn, for all harmonics of the 60 Hertz fundamental frequency. See paragraph 2.1 DBm plus 90 equals dBrn.

2.4.2 Where the test set meter face does not contain a dBm scale, the readings will be in volts. While a voltage scale has been included in the analysis chart (See Paragraph 3) these values are difficult to plot accurately. It is recommended that voltage magnitudes be converted to dBrn (power influence) before recording. Figure 4 has been prepared for easy conversion. To use, enter the chart at the measured voltage magnitude along the bottom horizontal scale and follow the vertical line from that point to the point it intersects the curve. Read the dBrn value of this point on the appropriate vertical scale.

2.4.3 Since the test set does not have noise measuring set capability it will be necessary to use a conventional noise measuring set to measure the C-message weighted power influence and circuit noise as discussed in Paragraph 2.3.4.

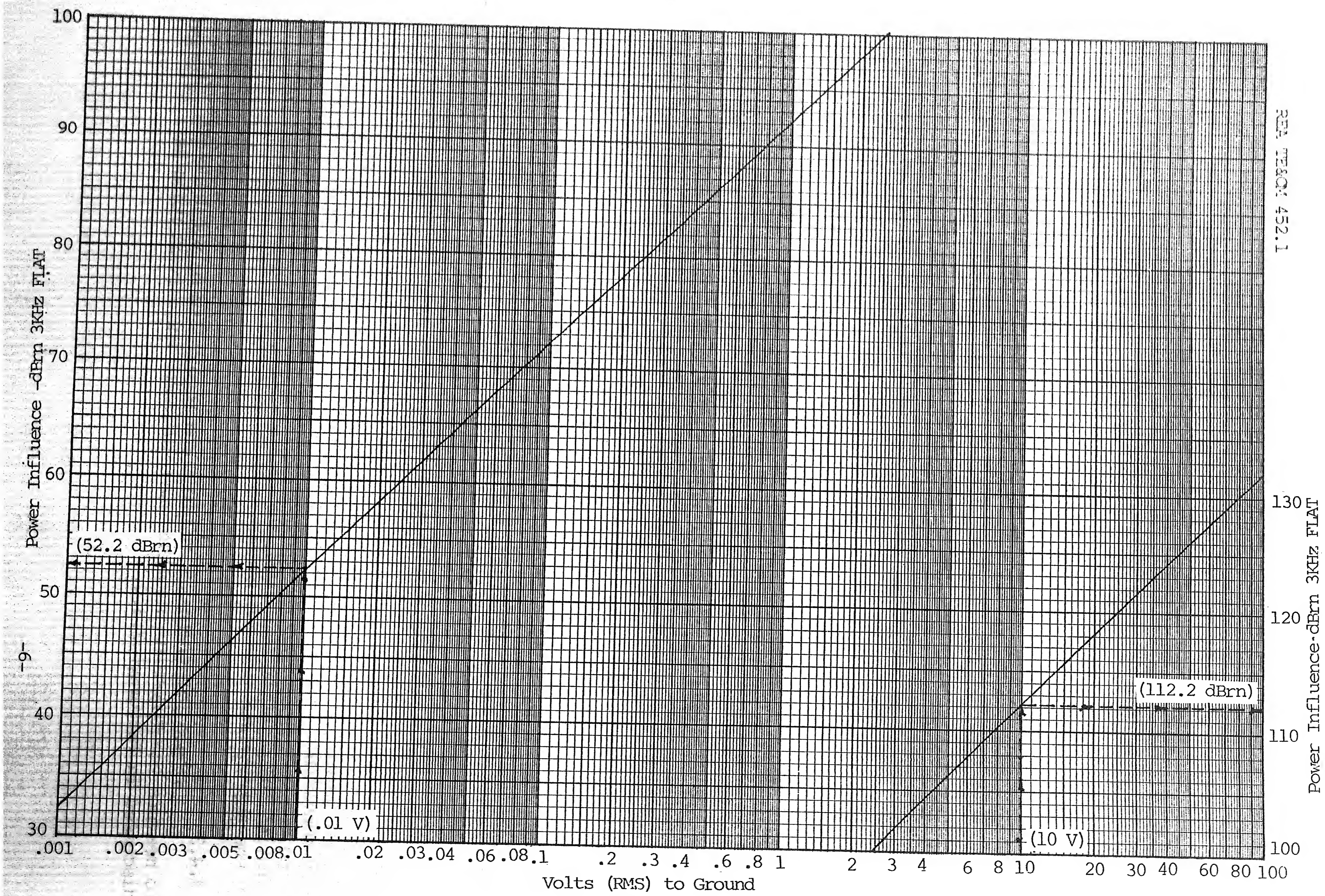


FIGURE 4
CONVERSION CHART
POWER INFLUENCE-dBrn 3 KHz FLAT TO VOLTS TO GROUND

3. ANALYSIS

3.1 The "Cable Pair Harmonic Analysis Matrix" shown in Figure 5 has been developed for graphical analysis of the harmonic content of cable pair power influence. Analysis is accomplished by relating the patterns formed by predominant harmonics to those indicating specific probable sources of noise.

3.1.1 The Sketch of Telephone and Power Facilities area (I) is used to record pertinent information relative to the physical makeup of the two facilities. Prepare a sketch showing the length of exposure, type of communications facility, type of power facility and separations between the two lines. Also include information regarding capacitor bank, voltage regulators, power substation and industrial plant locations. It is advisable to examine the power line beyond the length of actual exposure. Power system components in those areas can have a bearing on telephone system noise. Locations of capacitor banks beyond the ends of the exposure should always be noted.

3.1.2 The Level Graph (II) is based on statistical studies of subscriber loop noise surveys. An average or mean (μ) and upper standard deviation (σ) level (84% are statistically lower) are included for each harmonic frequency. A recorded value above the σ level ( ) is considered excessive. Recorded values falling between the σ and μ ( ) levels are in the marginal range. All values below the μ level are considered to be acceptable. Post the recorded results of measurements from the harmonic analysis data sheet (See paragraph 2.1.1) to the level graph. Include all harmonic frequencies with levels exceeding the mean values listed in column 3 of the data form. Plot the values from the initial measurement with an x. Results from subsequent measurements to determine the effectiveness of corrective actions are plotted with an ⊙ and ⊡ respectively.

3.1.3 The Correlation Matrix (III) is based on analysis of case studies and descriptions of harmonic producing components. Attempt by inspection to identify the closest match between the excessive and/or marginal harmonic levels plotted in the "Level Graph" and the circles in the matrix. Although perfect matches seldom occur, reasonable matches can often by identified and related to one or more probable sources. Noise problems are often associated with multiple power system sources which must be identified and corrected one at a time. (See paragraph 3.2 for a discussion of the analysis procedure).

3.1.4 The Probable Sources (IV) list is composed of the most common sources of power induced interference in telephone systems. They are related to the distinctive harmonic pattern associated with each specific source in the "Correlation Matrix". In some cases there are additional confirmation tests which may be completed by telephone company personnel prior to contacting the power company. In other cases measurements to verify the exact sources(s) and cause(s) must be made jointly with power company personnel.

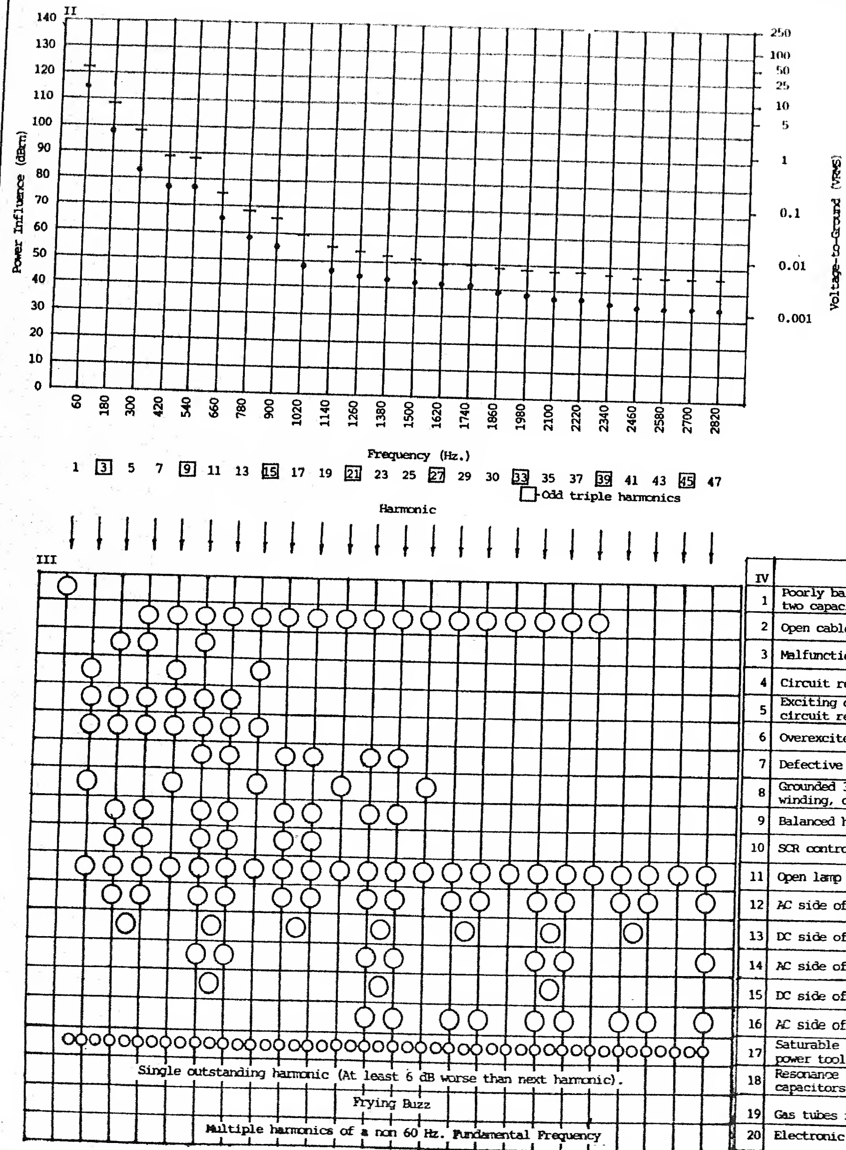
3.1.5 Refer to the Notes (V) when making any analysis. Information included in the notes can be valuable in determining the source of noise problem.

CABLE PAIR HARMONIC ANALYSIS MATRIX
(For problems not related to circuit balance, shield continuity or grounding)

Company ______________ Date ______________
Exchange ______________ Time ______________
Route ______________ Pair ______________
Tested by ______________

LEGEND
• Mean (μ)
μ ± δ
× First Test
⊙ Second Test
⊡ Third Test

I. DEPTH OF TELEPHONE AND POWER FACILITIES
Show: Mileage of both to nearest 1/10 mile; Type telephone facility, e.g. aerial & buried cable, open wire, etc.; Type power exposure, number of phases, Delta, Y-MGN, etc., capacitor bank locations, etc.



V

1. Sometimes accompanied by carbon block dusting or shorting. May also produce gas tube firing.
2. For long single exposures, a 1:1 power transformer may provide a solution.
3. Sometimes caused by open fuses protecting capacitors connected to one or two phase wires.
4. Each higher harmonic deviating more from the mean (assumes that all harmonics are at the same level). This is not always the case.
5. The 420 or 660 Hz. harmonic frequency may not appear predominately.
6. Usually occurs below the 15th harmonic. Can often be improved by relocating capacitors nearer to substation, installation of resonant shunt in capacitor bank ground wire or using a nongrounded (floating) capacitor configuration.
7. Seldom produces harmonics above the 13th.
8. Usually occurs during periods of low power demand.
9. Ninth harmonic (540 Hz) will often be predominant.
10. A high third harmonic may be due to ballast operated gaseous-discharge lamps (flourescent, mercury varpor, etc.).
11. Usually one (or two adjacent) sets of odd, nontriple harmonics.
12. Frequencies may not be exact harmonics of 60 Hz. which may be due to "slot" harmonics from induction motors. If a ripple (120 Hz. - from the resonance of two adjacent slot frequencies) is present, it may be caused by slot effects of "rolating field" generators.
13. One adjacent pair of nontriple harmonics is sufficient to suggest rectifier problems.
14. Usually occurs during periods of peak power demand.

IV	PROBABLE SOURCE	(V) SEE NOTES
1	Poorly balanced 3Ø power line, long exposure to single or 2Ø power circuits, or one or two capacitors of a 3Ø capacitor bank not functioning	1, 2, 3
2	Open cable shield	4
3	Malfunctioning capacitor bank(s)	5
4	Circuit resonance. Usually aggravated by capacitor bank(s)	6, 10
5	Exciting currents of silicon iron core distribution transformers. Can be aggravated by circuit resonance due to shunt capacitors	7
6	Overexcited power transformers	8, 9
7	Defective power step-down transformer	
8	Grounded 3Ø transformer, transformer either with an inadequate or without a tertiary winding, or a grounded-Y autotransformer	10
9	Balanced harmonics from generator, synchronous motor or condenser	11, 12
10	SCR control devices	
11	Open lamp on series street lighting circuit using individual transformers	
12	AC side of 6Ø rectifier or SCR control devices	13
13	DC side of 6Ø rectifier	
14	AC side of 6Ø rectifier	13
15	DC side of 12Ø rectifier	
16	AC side of other multiphase rectifier	13
17	Saturable reactor devices in 1Ø rectifiers, vapor lamps, welders, frequency changes, power tools, inductions heaters, etc.	10
18	Resonance in balanced or residual circuit of power system. Frequently due to shunt capacitors	6
19	Gas tubes firing. Often related to source 1 above.	14
20	Electronic frequency converters (cyclo converters)	

FIGURE 5

3.2 The analysis procedure entails determining which pattern(s) in the "Correlation Matrix" are best matched by the excessive and marginal harmonic frequency levels plotted in the "Level Graph". Then the probable sources associated with the pattern(s) will indicate the direction for continuation of the investigation.

3.2.1 First study the level graph and identify those harmonic frequencies exceeding the $\mu + \sigma$ limit. Number those with the greatest deviation by letting 1 = highest, 2 = next highest, etc. Post the dB value by which σ is exceeded.

3.2.2 Next fill in the matrix by placing an (X) in each circle associated with each harmonic frequency having a posted value greater than σ. Also place a single diagonal stroke (/) in each circle corresponding to a harmonic frequency with a posted value greater than μ and less than σ.

3.2.3 Now examine each horizontal line of the matrix for near correlations. On the lines identified lightly place an (X) or (/), as appropriate, in any harmonic frequency columns containing excessive or marginal posted levels which do not have a circle in the matrix.

3.2.4 Again study each line of the matrix to determine where the closest circle-by-circle match occurs. This is rarely a clear cut decision. When there are several near matches the one with the closest match must be identified.

3.2.4.1 Let each X=1 and each /=0.5. Each X or / in a circle is a match and each X or / that is not in a circle is a miss. Add the matches and misses along each horizontal line of the matrix where there is a near match. A circle which does not contain an X or / is counted a miss.

3.2.4.2 Calculate the correlation percentage by dividing the number of matches by the sum of the matches and misses. Enter the percentage at the end of the appropriate line in the matrix. Number the correlation percentages in sequence from the highest to the lowest. When there is a single predominant frequency Line 18 is number 1 regardless of other correlations. The most probable source of the noise problem is number 2, etc.

3.2.4.3 Assume, for example, a line in the matrix has ⊗ ○ / X ⊗ ⊘ (1 match, 1 miss, 0.5 miss, 1 miss, 1 match, 0.5 match). There are 2.5 matches and 2.5 misses. The correlation percentage is 2.5 divided by 5 equals 0.5 (50%).

3.2.4.4 This method for determining the nearest match is a guide to help identify a probable source. It must be tempered by judgement based on experience and additional considerations such as the notes in Part V of the matrix.

3.2.5 There will frequently be more than one power system source existing during a noise investigation. When a single probable source can be identified with the correlation percentage it is advisable to mitigate it first. Then make a second measurement of the harmonic frequencies. Plotting the results of the second measurement to the matrix will permit easier identification of the second source.

3.3 Conditions within a power system that produce distinctive harmonic frequency patterns in the telephone system power influence are generally related to capacitor, transformer and rectifier installations. There are other sources that are infrequently encountered during noise investigations. Some typical relationships are discussed below to aid in the decision process during noise investigations.

3.3.1 Shunt capacitors installed along power systems (See TE&CM Section 451, Paragraph 7.52), while not a source of harmonic frequencies, can contribute significantly to the severity of telephone system noise. Circuit resonance which is frequently aggravated by the presence of capacitor banks is indicated when the zero-sequence (odd-triple) third, ninth and fifteenth are in the marginal or excessive range as shown in line 4 of the matrix. Harmonic frequencies above the fifteenth harmonic seldom occur as a result of resonance. The ninth harmonic (540 Hz) will frequently be the predominant harmonic (6 dB or above the next worst harmonic. When this occurs the single outstanding harmonic condition of line 18 will be applicable.

3.3.1.1 A malfunctioning capacitor bank will produce a harmonic pattern similar to that illustrated in line 3 of the matrix. The fifth, seventh and eleventh harmonics will be in the marginal or excessive range. The fifth harmonics (300 Hz) may appear as a single predominant harmonic. Also the ninth harmonic may appear, with the three commonly found, as a predominant harmonic (See paragraph 3.3.1). A malfunctioning capacitor bank can occur when a capacitor accidently is left connected to a phase conductor during the removal of a three-phase capacitor bank. It may also occur if a fuse is blown removing one capacitor of a three-phase bank. The condition might also occur where a capacitor bank is switched in and out by a time clock. If one of the switch blades does not make good contact one of the capacitors may not be connected to the phase wire.

3.3.1.2 Some transformer related problems can be aggravated by capacitor bank installations. Among these are distribution transformers with a silicom iron core (See paragraph 3.3.2.1).

3.3.2 The transformers installed along power systems can be a source of fundamental frequency harmonics which may interfere with nearby telephone systems. (See TE&CM Section 451, Paragraph 7.51). An overexcited transformer primary winding (Excessive primary voltage level) will produce harmonics. As illustrated in line 6 of the matrix the odd harmonics from the third through the fifteenth (180 through 900 Hz) are likely to exceed (μ). The transformer primary voltage levels are usually set to provide the correct secondary voltage during periods of high power demand. When the demand is low the primary voltage levels may exceed those that result in efficient operation and harmonics are produced. The ninth harmonic (540 Hz) will often be found as the predominant frequency.

3.3.2.1 Excitation currents in power transformers with silicon iron cores may also produce harmonic frequencies. Sometimes these harmonics are aggravated by circuit resonance and capacitor banks. The harmonic frequencies exceeding μ will usually produce a pattern similar to the one shown in line 5 of the matrix. Excessive values will seldom be found above the thirteenth harmonic (780 Hz).

3.3.2.2 A defective step-down power transformer will produce a harmonic frequency pattern similar to that shown in line 7 of the matrix.

3.3.2.3 A harmonic frequency pattern similar to the one illustrated on line 8 of the matrix will likely be due to a grounded three-phase transformer, a grounded-Y auto-transformer or a transformer that is not equipped with or has an inadequate tertiary winding. A tertiary winding is normally used on transformers installed at substations. The terminals of the tertiary winding may or may not be brought out on bushings to permit using the voltage output.

3.3.3 Multiphase rectifiers such as used with high voltage direct current (HVDC) transmission lines produce a different pattern. (See TE&CM Section 451, Paragraph 7.7). Line 12 of the matrix illustrates the harmonic pattern appearing on the ac side of a six-phase rectifier. This same pattern is sometimes associated with an SCR control device (See also paragraph 3.3.4.4).

3.3.3.1 The harmonic pattern appearing on the dc side of a multiphase rectifier is conspicuous because it consists of all even harmonics. The lowest harmonic is equal to the number of phases in the rectifier. The pattern found on the dc side of a six-phase rectifier is illustrated in line 13 of the matrix.

3.3.3.2 When the harmonic source is a twelve-phase rectifier the pattern on the ac side is similar to the one for six-phase rectifier shown on line 12 except the fifth and seventh, the seventeenth and nineteenth, etc., harmonics (300, 420, 1020, 1140 Hz. etc) are no longer present. The pattern appearing on the ac side of a twelve-phase rectifier is shown on line 14.

3.3.3.3 The harmonic pattern appearing on the dc side of a twelve-phase rectifier consists of all even harmonics as was discussed for six-phase rectifiers in paragraph 3.3.3.1. The pattern is shown in line 15 of the matrix.

3.3.3.4 A pair of adjacent nonzero-sequence harmonics above the twenty third (1380 Hz) are usually due to a multi-phase rectifier installation. These patterns which will appear on the ac side of the rectifier are shown in line 16 of the matrix.

3.3.3.5 A string of consecutive odd and even harmonics such as shown in line 17 of the matrix may be due to the presence of saturable reactor devices in a single phase rectifier. There are other devices which can produce the same pattern such as "vapor" lamps, welders, frequency changers, power tools, induction heaters, etc.

3.3.4 There are other distinctive patterns which can indicate a harmonic frequency source from other than an identifiable component of the power system. Such sources might be associated with customer owned devices connected to either the power or telephone system. One pattern often found is illustrated in line 1 of the matrix where the fundamental frequency (60 Hz) component appears as a single outstanding frequency. This is usually the result of a poorly balanced three-phase power system parallel to the telephone plant. It might also be due to a long parallel exposure to a single-phase power circuit. Sometimes it can occur when one or two capacitors of a three-phase capacitor bank are not working.

3.3.4.1 When an open shield exists along the telephone cable a string of odd harmonic frequencies will be found as illustrated in line 2 of the matrix. If the open cable shield is the predominant problem the harmonic frequency levels will be essentially the same difference from the mean levels.

3.3.4.2 Balanced harmonics from a generator, synchronous motor or condensor will usually produce one or two adjacent pairs of odd nonzero-sequence harmonics of those shown in line 9. Where the frequencies are not precise harmonics of 60 Hertz, "slot" harmonics from an induction motor may be indicated.

3.3.4.3 An open lamp on a series street lighting circuit employing individual transformers will produce a string of odd harmonics up to about 3000 Hertz. The resulting harmonic pattern will be similar to the one shown in line 11 of the matrix.

3.3.4.4 Silicon controlled rectifier (SCR) control devices will usually produce a harmonic frequency pattern as shown in line 10 of the matrix. In some cases the pattern may resemble that shown in line 12.

3.3.4.5 When multiple harmonics are found that are not harmonics of the 60 Hertz fundamental frequency they are likely due to the electronic frequency converters (cyclo converters).

4. EXAMPLE

4.1 The example assumes a noise problem exists along a cable route and measurement of the power influence harmonic frequency levels has been completed at a subscriber station protector. The results of these measurements are recorded on a Harmonic Analysis Data Sheet as shown in Figure 6. Also make a sketch of the exposure in the appropriate area (I) of the Cable Pair Harmonic Analysis Matrix (Figure 7).

4.1.1 Enter in the level graph (II) of the Cable Pair Harmonic Analysis Matrix those harmonics with recorded values equal to or exceeding the mean values listed in column 3 of the data sheet as shown in Figure 7. Study the level graph to determine if there are predominant frequencies. Four frequencies are found in Figure 7 that exceed the σ limit by a greater margin than all others. The ninth harmonic (540 Hz.) exceeds σ by 25 dB so mark this

HARMONIC ANALYSIS DATA SHEET

Company Alpha Date 10/15/79

Exchange Beta Time 9:00 a.m.

Route A2 PED A2-30 Pair 152

Tested By DOC

Harmonic	1. Freq. Hz	2. PI Level (Ng+40) (dBrn 3KHz)	3. Disregard If Levels Are Less Than (dBrn 3KHz)	Harmonic	1. Freq. Hz	2. PI Level (Ng+40) (dBrn 3KHz)	3. Disregard If Levels Are Less Than (dBrn 3KHz)
1	60	110	115	37	2220		37
2	120		106	38	2280		36
3	180	103	97	39	2380		35
4	240		92	40	2400		35
5	300	92	83	41	2460		34
6	360		80	42	2520		34
7	420	98	77	43	2580		34
8	480		77	44	2640		34
9	540	112	77	45	2700		34
10	600		70	46	2760		34
11	660	70	65	47	2820		34
12	720		61				
13	780	74	58				
14	840		57				
15	900	80	55				
16	960		51				
17	1020	65	48				
18	1080		47				
19	1140	58	46				
20	1200		45				
21	1260	51	44				
22	1320		43				
23	1380	50	43				
24	1440		42				
25	1500	33	42				
26	1560		41				
27	1620	44	41				
28	1680		41				
29	1740	45	41				
30	1800		40				
31	1860	31	39				
32	1920		39				
33	1980		38				
34	2040		38				
35	2100		37				
36	2160		37				

Overall Noise Measurement

3kHz.

Power Influence (Ng+40)	115.0	dBrn
Circuit Noise (Nm)	44.0	dBrn
Balance	71.0	dB

C-Msg.

Power Influence (Ng+40)	105.5	dBrnc
Circuit Noise (Nm)	28.0	dBrnc
Balance	77.5	dB

FIGURE 6

EXAMPLE-DATA SHEET-FIRST MEASUREMENT

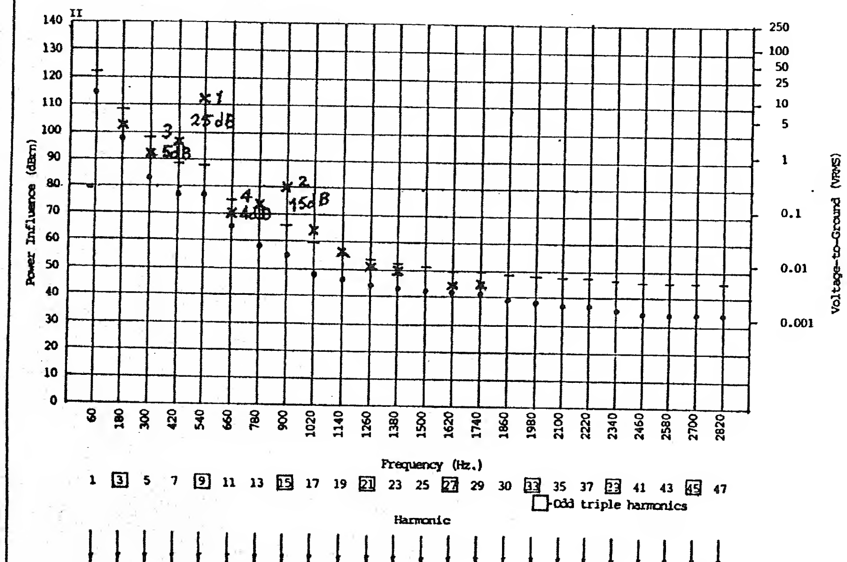
CABLE PAIR HARMONIC ANALYSIS MATRIX
(For problems not related to circuit balance, shield continuity or grounding)

Company Alpha   Date 10/15/79
Exchange Beta   Time 9:00 a.m
Route A2 PED A2-30   Pair 152
Tested by DOC

LEGEND
• Mean (L)
+ L + 6
x First Test
⊙ Second Test
⊡ Third Test

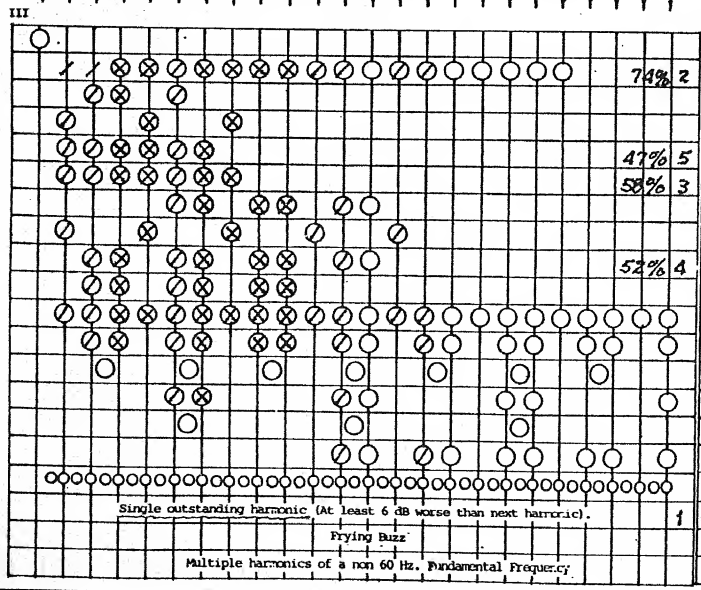
I. SKETCH OF TELEPHONE AND POWER FACILITIES
Show: Mileage of both to nearest 1/10 mile; Type telephone facility, e.g. aerial & buried cable, open wire, etc.; Type power exposure, number of phases, Delta, Y-MGN, etc., capacitor bank locations, etc.

Substation 7.6kV. Y-MGN 3Ø   1Ø   1Ø
Separation 60' 30' 60'
CO
Test Point
Ped A2-30
X = L.P



V

1. Sometimes accompanied by carbon block dusting or shorting. May also produce gas tube firing.
2. For long single exposures, a 1:1 power transformer may provide a solution.
3. Sometimes caused by open fuses protecting capacitors connected to one or two phase wires.
4. Each higher harmonic deviating more from the mean (assumes that all harmonics are at the same level). This is not always the case.
5. The 420 or 660 Hz. harmonic frequency may not appear predominately.
6. Usually occurs below the 15th harmonic. Can often be improved by relocating capacitors nearer to substation, installation of resonant shunt in capacitor bank ground wire or using a nongrounded (floating) capacitor configuration.
7. Seldom produces harmonics above the 13th.
8. Usually occurs during periods of low power demand.
9. Ninth harmonic (540 Hz) will often be predominant.
10. A high third harmonic may be due to ballast operated gaseous-discharge lamps (flourescent, mercury varpor, etc.).
11. Usually one (or two adjacent) sets of odd, nontriple harmonics.
12. Frequencies may not be exact harmonics of 60 Hz. which may be due to "slot" harmonics from induction motors. If a ripple (120 Hz. - from the resonance of two adjacent slot frequencies) is present, it may be caused by slot effects of "rotating field" generators.
13. One adjacent pair of nontriple harmonics is sufficient to suggest rectifier problems.
14. Usually occurs during periods of peak power demand.



IV	PROBABLE SOURCE	(V) SEE NOTES
1	Poorly balanced 3Ø power line, long exposure to single or 2Ø power circuits, or one or two capacitors of a 3Ø capacitor bank not functioning	1, 2, 3
2	Open cable shield	4
3	Malfunctioning capacitor bank(s)	5
4	Circuit resonance. Usually aggravated by capacitor bank(s)	6, 10
5	Exciting currents of silicon iron core distribution transformers. Can be aggravated by circuit resonance due to shunt capacitors	7
6	Overexcited power transformers	8, 9
7	Defective power step-down transformer	
8	Grounded 3Ø transformer, transformer either with an inadequate or without a tertiary winding, or a grounded-Y autotransformer	10
9	Balanced harmonics from generator, synchronous motor or condenser	11, 12
10	SCR control devices	
11	Open lamp on series street lighting circuit using individual transformers	
12	AC side of 6Ø rectifier or SCR control devices	13
13	DC side of 6Ø rectifier	
14	AC side of 6Ø rectifier	13
15	DC side of 12Ø rectifier	
16	AC side of other multiphase rectifier	13
17	Saturable reactor devices in 1Ø rectifiers, vapor lamps, welders, frequency changes, power tools, inductions heaters, etc.	10
18	Resonance in balanced or residual circuit of power system. Frequently due to shunt capacitors	6
19	Gas tubes firing. Often related to source 1 above.	14
20	Electronic frequency converters (cyclo converters)	

FIGURE 7

EXAMPLE-MATRIX-FIRST MEASUREMENT

#1 as shown. The fifteenth (900 Hz), seventh (420 Hz) and thirteenth (780 Hz) harmonics exceed σ by 15, 5 and 4 dB so mark them 2, 3 and 4 respectively. Since the 500 Hertz component exceeds the next highest harmonic level by more than 6 dB it is a single outstanding harmonic frequency. Place the number 1 next to the line number 18 and place a circle around the 18 indicating this is the best match.

4.1.2 Next fill in the correlation matrix III by placing an (X) or (/) in each circle below a harmonic frequency with a plotted value in the level graph higher than the indicated μ. (See paragraph 3.2.2) Study the matrix. In the example there appear to be possible correlations with lines 2, 5, 6, and 9. It might appear that there are other likely correlations but these can be ruled out by considering the number of plotted values which have no circles in the matrix. Place an (X) or (/) under each harmonic frequency with a plotted value in the level graph higher than μ on lines 2, 5, 6, and 9 where there is no circle.

4.1.3 Calculate the correlation percentages as discussed in paragraphs 3.2.4.1 and 3.2.4.2. In line 2 there are 8.5 hits and 3 misses. 8.5 divided by 11.5 equals 0.739 or 74 percent. Line 5 has 4.5 hits and 5 misses. 4.5 divided by 9.5 equals 0.474 or 47 percent. There are 5.5 hits on line 6 and 4 misses. 5.5 divided by 9.5 equals 0.579 or 58 percent. In line 9 there are 5.5 hits and 5 misses. 5.5 divided by 10.5 equals 0.524 or 52 percent. Enter the correlation percentages at the right hand end of the appropriate line in the matrix next to the line number. Based on the correlation percentages line 2 is numbered 2, line 6 numbered 3, line 9 numbered 4 and line 5 numbered 5. The line numbers 2, 5, 6 and 9 are circled.

4.2 Since the 540 Hertz component (9th harmonic) is predominant and there is a capacitor bank installed along the three phase power system as shown in the sketch this should be investigated first. This course of action is supported by the correlation of line six since in the event of overexcited transformers the 540 Hertz component is often pre-sominat. While it appears there may be an open shield this might not be a valid indication in the presence of the single dominant frequency.

4.2.1 Investigation of the effects of a capacitor bank on the power system can be accomplished by monitoring the magnetic field intensity of the predominant harmonic frequency with an exploring coil along the power line. This will usually verify that if the harmonic frequency current appears to be flowing to ground at the capacitor bank. Then the magnitude of the earth return current can be measured with an exploring coil at various locations along the power line. The recorded results of these measurements provide information which will be meaningful to power company engineers during inductive coordination meetings. These techniques for studying the power system are discussed in detail in TE&CM Section 452.2.

4.2.2 For the purposes of this example it will be assumed an apparent resonance is found in the power system with a low impedance to ground through the capacitor bank ground connection. The measured earth return current of the power system between the capacitor bank location and the power substation is 0.8 amperes. This establishes adequate evidence of a power system problem justifying a dialogue with the power company.

4.3 Contact the power company and present to them the data obtained relative to the earth return current. When they concur with the principal of a possible power system related problem arrange for the temporary removal of the ground connection to the capacitor bank. During the period the ground connection is removed remeasure the power influence harmonic frequency levels at the same subscriber station protector as in paragraph 4.1. The recorded results of these measurements for the example are recorded on a Harmonic Analysis Data Sheet as shown in Figure 8.

4.3.1 Enter in the level graph (II) of the Cable Pair Harmonic Analysis Matrix those harmonics from the remeasurement with recorded values equal to or exceeding the mean values listed in column 3 of the data sheet as shown in Figure 9. Study the level graph to determine if there are any predominant frequencies and compare it to the level graph from the initial measurements to determine if changes are evident. There is no longer a single predominant frequency. The eleventh (660 Hz) and fifteenth (900 Hz) harmonics exceed σ by 5 dB and the ninth (540 Hz) by 4 dB. This is a definite improvement over the initial results and proves the capacitor bank was contributing to the overall telephone system noise problem.

4.3.2 Next fill in the correlation matrix as shown in paragraph 4.1.2. Study the matrix. There appears to be possible correlations with lines 2, 5, and 6. These three lines also appeared as potential correlations during the analysis of the initial measurements.

4.3.2 Calculate the correlation percentages as was done for the initial measurements (See paragraph 4.1.3). In line 2 there are 6.5 hits and 5.5 misses. 6.5 divided by 12 equals 0.542 or 54 percent. Line 5 has 5 hits and 3 misses. 5 divided by 8 equals 0.625 or 63 percent. There are 6 hits and 2 misses on line 6. 6 divided by 8 equals 0.75 or 75 percent. Enter the correlation percentages at the right hand end of the appropriate line in the matrix next to the line number. Based on the calculated correlation percentages on lines 6, 5, and 2 enter number 1, 2 and 3 respectively and circle the line numbers.

4.4 It is evident that the removal of the capacitor bank ground connection has reduced the power influence in the telephone system. This can be further verified by measurement of the 540 Hertz earth return current along the power line. For the purposes of the example it is assumed that recorded results of the earth current measurements show there is now only 0.02 amperes flowing between the capacitor bank location and the power substation.

4.4.1 There has been a significant reduction in the correlation percentage associated with line 2 (open cable shield). The possibility of an open cable shield need no longer be considered. A significant increase in correlation percentage appears in lines 5 and 6 which relate to transformer excitation. The presence of overexcited power transformers cannot be proven without the assistance of power company personnel.

4.4.2 Contract the power company and discuss with them the data obtained during the period the ground connection to the capacitor bank was removed. While there is conslusive evidence that the capacitor bank is a major contributor to the overall noise problem the decision as to what to do

HARMONIC ANALYSIS DATA SHEET

Company *Alpha* Date *10/16/79*

Exchange *Beta* Time *11:00 am.*

Route *A2* *PED A2-30* Pair *152*

Tested By *DOC*

Harmonic	1. Freq. Hz	2. PI Level (Ng+40) (dBrn 3KHz)	3. Disregard If Levels Are Less Than (dBrn 3KHz)
1	60	*110*	115
2	120		106
3	180	*100*	97
4	240		92
5	300	*100*	83
6	360		80
7	420	*90*	77
8	480		77
9	540	*92*	77
10	600		70
11	660	*79*	65
12	720		61
13	780	*61*	58
14	840		57
15	900	*72*	55
16	960		51
17	1020	*52*	48
18	1080		47
19	1140	*40*	46
20	1200		45
21	1260	*50*	44
22	1320		43
23	1380	*40*	43
24	1440		42
25	1500	*30*	42
26	1560		41
27	1620	*45*	41
28	1680		41
29	1740	*45*	41
30	1800		40
31	1860	*31*	39
32	1920		39
33	1980		38
34	2040		38
35	2100		37
36	2160		37
37	2220		37
38	2280		36
39	2380		35
40	2400		35
41	2460		34
42	2520		34
43	2580		34
44	2640		34
45	2700		34
46	2760		34
47	2820		34

Overall Noise Measurement

3kHz.

Power Influence (Ng+40)	*112.5*	dBrn
Circuit Noise (Nm)	*43.5*	dBrn
Balance	*69.0*	dB

C-Msg.

Power Influence (Ng+40)	*89.0*	dBrnc
Circuit Noise (Nm)	*12.5*	dBrnc
Balance	*76.5*	dB

FIGURE 8

EXAMPLE-DATA SHEET-SECOND MEASUREMENT

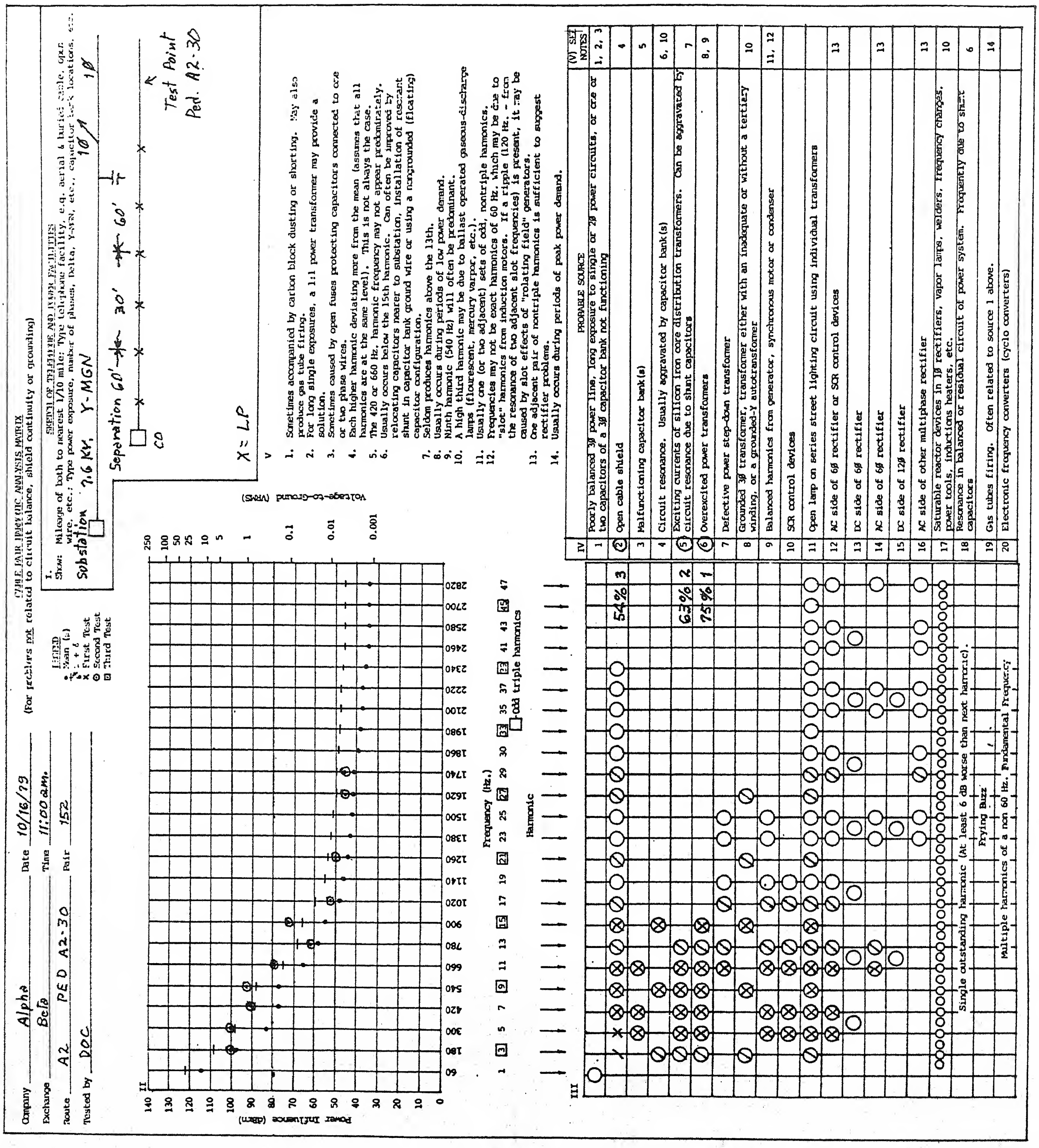


FIGURE 9

EXAMPLE-MATRIX-SECOND MEASUREMENT

about the bank should be left to the power company. There are two courses of action they might take, relocate the capacitor bank closer to the power substation or install a harmonic shunt in the ground lead to the bank. Power company personnel may wish to make measurements along the power line to confirm there is excess voltage in the transformer primary windings.

4.4.3 There might be some question as to why the possible problem of overexcited transformers should be explored. The overall C-message weighted noise measurements on the data sheet (Figure 8) shown circuit noise level of 12.5 dBrnc which is within the objective limits. This is only possible because of the excellent balance of this cable circuit. It is likely that other pairs in the cable will not have balance this high. A cable pair with an acceptable balance of 60 dB would have a circuit noise of 29 dBrnc. Since the power influence is 89.0 dBrnc which is in the high marginal range it is wise to try and reduce it to 80 dBrnc or lower, if possible.

4.4.4 For the purpose of the example it is assumed that the power company relocated the capacitor bank closer to the substation and reduced the primary voltage of the power line at the substation. Make a final measurement of the C-message weighted noise at the same location as the previous two measurements to determine the effects of the power company work. These recorded results show power influence -81 dBrnc and circuit noise -9 dBrnc for a balance of 72 dB. This is not a true reduction in balance. The induced circuit has been reduced below the threshhold of the steady state noise of the central office at the point of measurement. This noise investigation can now be closed.

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